WIND TURBINES AND BAT MORTALITY: INTERACTIONS OF BAT ECHOLOCATION PULSES WITH MOVING TURBINE ROTOR BLADES

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1 ABSTRACT

Wind power is a rapidly growing energy technology, popular for being a clean, reliable and cost-efficient renewable energy source. However, recently concern has been growing over the impact of wind turbines on flying wildlife, with both birds and bats found dead around turbine bases and observed collisions with moving turbine rotors. This phenomenon is widespread and has received enough attention to warrant investigation into how and why these collisions occur. In this paper we investigate the acoustic interaction of bats with wind turbines, in particular the interpretation of reflected sound pulses (echolocation) used by bats to navigate. This paper focuses on the effects of moving turbine rotor blades on reflected acoustic pulses, analogous to what might be presented to an echolocating bat approaching an operational turbine at rotor height. High frequency, simulated FM bat pulses were used to assess reflected echo properties from microturbines (experimentally and in simulation) in order to investigate what interaction rotor movements had with incoming pulses and the potential consequences for an echolocating bat near a moving wind turbine.

2 INTRODUCTION

Wind energy is the fastest growing global energy technology, with a yearly growth rate of around 30 % (BWEA 2001). Energy harnessed from the wind is reliable, cost-effective and without the drawbacks of nuclear and fossil fuels, and for these reasons the UK government alone has set a target to generate 10 % of all UK electricity from renewable sources by 2010 (BWEA 2001). Although wind turbines have undergone 30 years of development only recently has concern been growing over the impact of turbines on winged animals such as birds and, perhaps more interestingly from an acoustic point of view, bats. The reasons why bats are apparently unable to 'see' the moving rotors of wind turbines, or avoid them, remain unclear. The incidence of bat-turbine interaction provides an interesting problem from an acoustic and also an engineering point of view, and it is clear an immediate solution is needed not only to minimise impact on existing bat populations (particularly for endangered species), but also to negate complications with the development of wind energy.

It is not currently known why bats are unable to avoid wind turbines; research has identified significant levels of bat injury and death due to turbine collisions (Williams 2007) but the impact of this on individual bat populations globally remains unknown (Westaway 2007). Bat-turbine interaction fatalities seem to be both incidental and where bats appear to be attracted to the turbine blades (Westaway 2007), and it is clear a more thorough understanding of the situation is required. While many industry studies primarily focus on large scale turbines at wind plants, smaller turbines also have a part to play in bat mortality. In 2004 there were 650 microturbines (blade diameter <2 m) installed in the UK (DTI 2006), and by 2050 microgeneration could provide 30-40 % of the UK's electricity needs (DTI 2006). The Bat Conservation Trust (BCT) (2006), a UK organisation, has "anecdotal evidence" of bat deaths caused by microturbines (see also BCT, 2007), but "very little" research has been carried out in this area to date (Williams 2007). The BCT (2007) (Williams 2007) warns that the cumulative effects of large scale turbines and microturbines on native UK bat populations could be significant. The increasing demand for wind energy requires a rapid investigation into potential problems and solutions for species affected (Nicholls Racey 2007). It is widely acknowledged that there is a concern in the impact of newly installed turbines in the UK as a “biodiversity” question is typically included on turbine planning applications. However, there are moves to make microturbines Permitted Developments (i.e. requiring no planning permissions) in 2009, and hence this safeguard would be bypassed (BCT 2006).

Bats frequent urban areas due to the availability of roost sites and gardens or street lamps for foraging (Walsh Harris 1996), hence the proliferation of microturbines could cause a serious detriment to bat numbers. In the Eastern US most large turbines are installed in grassland, agricultural and desert land, and in the Western US turbines are located along forested ridge tops (Kunz etal 2007). Bats are also observed to frequently forage over open meadow land (Walsh Harris 1996), just such areas where larger turbines are likely to be located. While the National Wind Coordinating Collaborative (NWCC) (2007) recognises that completely avoiding turbine-wildlife mortality is an unrealistic expectation, there may be ways to reduce the impact significantly given a greater understanding of the problems surrounding this area. Many bat organisations have underlined the urgent need for more research into the effects of wind turbines on bats, such as The BCT (2006) and Eurobats (2003). Research is needed to understand where, when, how and why bats are killed by turbines (Kunz etal 2007), and in all cases research is required to investigate the factors involved in bat attraction to wind turbines (Westaway 2007).

3 METHODOLOGY

A simulated FM bat pulse, created in MatLab was used modelled on that of the common pipistrelle (*Pipistrellus pipistrellus*), due to the abundance of the species in the UK and since the species has previously been identified as being at ‘high risk’ of wind turbine interaction due to its aerial hawking feeding strategy (Betts 2006). The properties of the signal were very closely matched in terms of frequency of highest energy, pulse modulation, duration and amplitude variation over time (see *Figure 1).

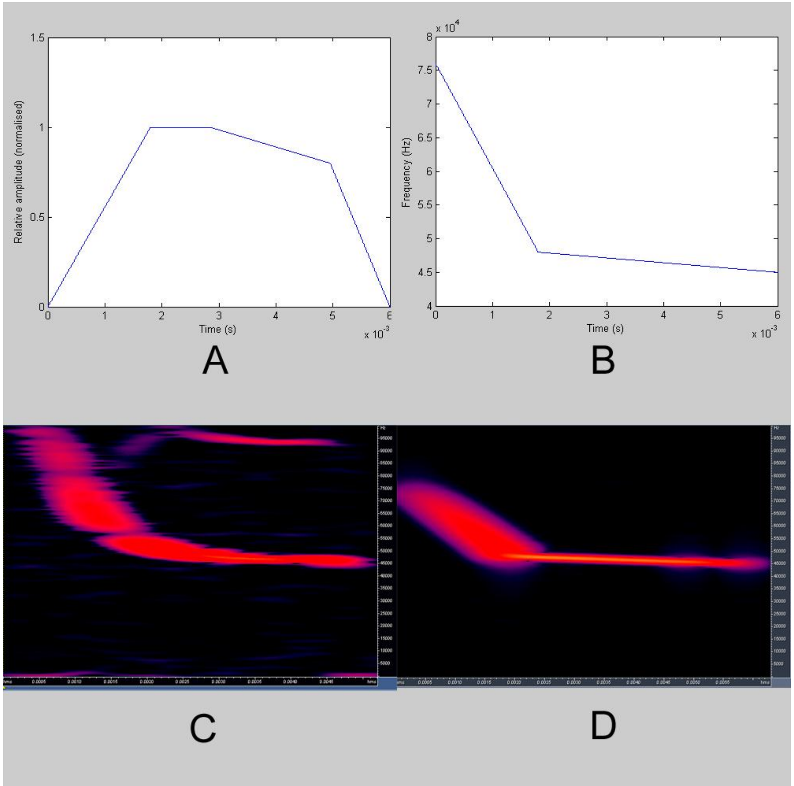

Figure 1: (*TEMP FIG) Demonstrating parameters for the simulated *Pipistrellus* pulse. A- Variation in pulse relative amplitude over pulse duration; B- Variation in pulse frequency over pulse duration; C- Example sonogram of a real pipistrelle pulse (including harmonic); D- Example sonogram of the artificial pulse. Windowing: Backmann-Harris, 256 band resolution.

The pulse code was output via a National Instruments USB-6251 data acquisition card at a high sampling rate of 800 kS s^{-1}. The pulse emitter was a high-frequency Clarion® SRU310H silk dome tweeter, with a frequency range of 2 - 80 kHz, connected to a power amplifier to boost the emitted signal to 90 dB peak SPL (re 20 μPa) at a distance of 0.5 m, analogous to the level of a real pipistrelle call (Waters and Jones 1995). Data were simultaneously emitted and received via the DAQ card, the receiver being a calibrated GRAS 40BF ¼" free-field microphone with a flat response between 2 Hz - 100 kHz, sampled at 200 kS s^{-1}. The emitter and receiver (source) were clamped in horizontal juxtaposition and placed at one end of an anechoic chamber; at the other end a Marlec Rutland 913 Windcharger microturbine (6 blades; diameter 0.91 m) was positioned. The precise distance to the blade edge and hub was measured (either 0.5 or 1 m from source) and the source aligned with turbine blades using laser guidance. The turbine was placed in one of two positions (see *Figure 1); horizontal to the source (pulses reflected from blade fronts) or lateral to the source (pulses reflected from blade tip edges). A fan was positioned either behind or to the side of the source (depending on turbine measurement position) and was used to drive the turbine rotor prior to measurement; the turbine was also tethered from the rear to keep blades fixed in the measurement plane. Shortly before measurement, the fan was switched off and the blades allowed to naturally slow slightly to 17.5 rad s^{-1} as measured with a stroboscope, at which point measurements were started.

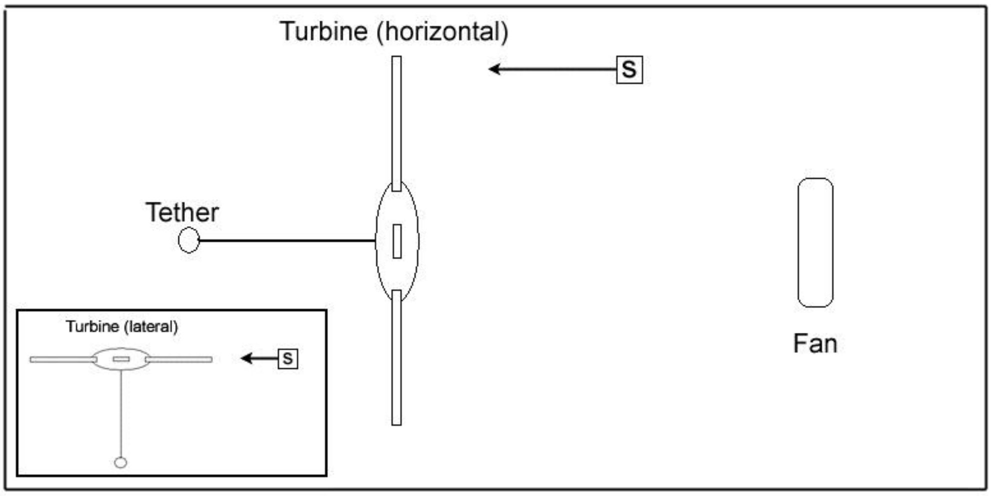

Figure 1: (*TEMP FIG) Anechoic room setup for experimental data collection. *S* denotes source, positioned either 0.5 or 1 m from turbine blades.

During measurement, the microphone recorded continuously for 5 s while a series of simulated bat pulses were emitted from the source over a period of 1 s. Each pulse was emitted 36 ms apart, corresponding to 28 pulses per session. This interval was chosen as it allowed ample time for echo return to be detected before the succeeding pulse, and was assumed to be similar to those pulse rates used by a foraging pipistrelle bat. The variation in speed of the slowing blade was felt to be negligible over the measurement period. Prior to each experimental run, control measurements were taken to verify the speed of sound in the chamber and to test pulse reflection from stationary turbine blades in each position. Speed of sound was tested by placing a specular surface exactly 1 m from the source and measuring the time taken for the emitted echo to return to the source; temperature and relative humidity were simultaneously recorded via a digital 4-in-1 meter. All measurement recordings were saved direct to PC in uncompressed (.wav) format, processed and analysed in Adobe Audition 1.0 and MatLab respectively. To calculate energy lost in reflected echoes, 1 ms of the pulse was selected, converted to FFT and compared to the FFT of an outgoing pulse measured directly at 0.5 m and to that of a pulse reflected from a specular surface at 0.5 m. To ensure the measurement was taken at the same portion of the pulse each time, the end of the pulse was selected where the energy was highest at 46 kHz and no pulse overlap was present.

4 RESULTS

Speed of sound in the chamber was found to be 341.88 m s^{-1} at 21.2 °C and 30.9 % Relative Humidity, which corresponded well with the expected value at these environmental conditions.

4.1 HORIZONTAL MEASUREMENTS

During the control measurements, all emitted pulses were reflected back to the source at distances of both 0.5 m and 1 m from source to blade face, with an average distance error of ±0.01 m at 0.5 m and ±0.03 m at 1 m. Pulses emitted from 0.5 m at the turbine blades, rotating at 17.5 rad s^{-1}, were found to be reflected back to the source with varying degrees of scatter. Pulses emitted from 1 m toward the blades, rotating at 17.5 rad s^{-1}, were subject to a more complex scattering effect, due to source directivity insonating a greater area of the rotating blade but potentially reduced specular target strength at non-normal incidence angle. This combined with increased spreading losses at the greater range resulted in more variable, weak echoes compared to the shorter range measurements. There was found to be no effect on perceived distance to turbine blades, Doppler shift of frequency of highest energy or marked pulse distortion (other than scattering) with horizontal blade rotation.

4.2 LATERAL MEASUREMENTS

During the control measurements, all emitted pulses were reflected back to the source at a distance of 0.5 m from source to blade tip edge, with an average distance error of ±0.01 m. At a distance of 1 m, however, no pulse reflections were detected in the control measurement other than that from the turbine blade hub. Pulses emitted from 0.5 m at the turbine blades, rotating at 17.5 rad s^{-1}, were found to be selectively reflected. *Figure 3 below shows the spectrogram of a sample from these lateral measurements, highlighting those emitted pulses in which an echo was reflected back to the source. On average, only 8.9 % of emitted pulses in one second of pulse emission were found to have discernable echoes at this distance (5.3 % per blade sweep). As with the control, at a distance of 1 m no emitted pulse echoes were detected while the blades were rotating at 17.5 rad s^{-1}. At 0.5 m only, there was found to be no effect on perceived distance to turbine blades, Doppler shift of frequency of highest energy or marked pulse distortion (other than scattering) with horizontal blade rotation.

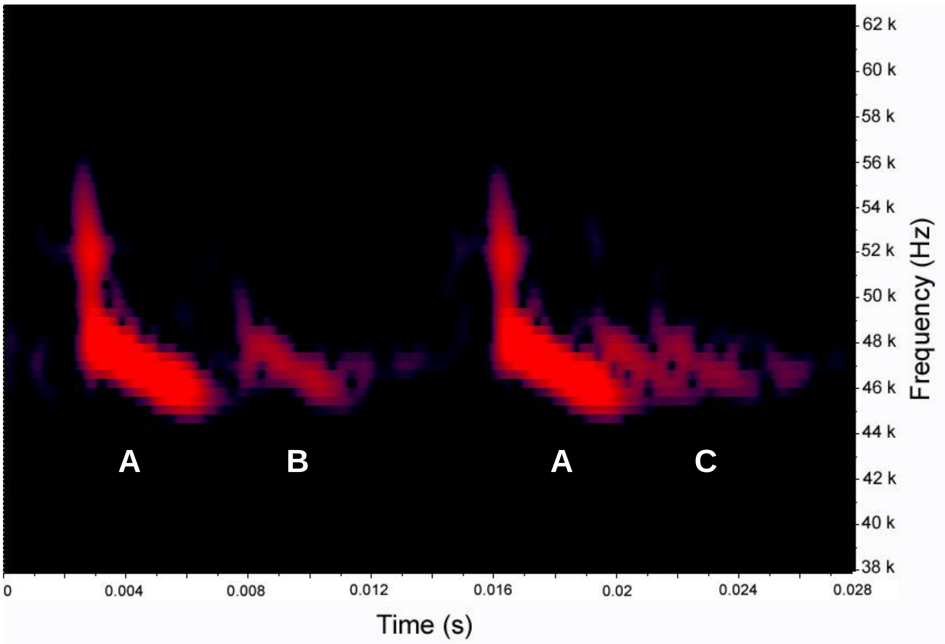

Figure 3: (*TEMP FIG) Example spectrogram for outgoing pulses (A) and echoes reflected from the turbine (B;C) lateral to source at a distance of 0.5 m. Note that although a consistent echo is returned from the hub (B), an echo from the blade tips is returned infrequently (C). Delay between pulses does not represent actual experimental delay. Windowing: Backmann-Harris, 256 band resolution.

4.3 PROBABILITY CALCULATIONS

In order to provide a comparison for the pulse reflection data, Equation (1) calculates the probability, P that an incoming echolocation pulse would be reflected back to the source by coinciding with blade sweeps. Consider a turbine of blade width W, number of blades N, period of rotation ω (in rad s^{-1}) and distance from hub centre x. Echolocation pulse call length is represented by t_c.

$$P = \frac{WN}{2\pi x} + \frac{\omega N t_c}{2\pi} \quad (1)$$

Therefore a longer pulse length, faster blade rotation, larger blade width and more blades all increase the probability of echo reflection in any one blade sweep cycle. By substituting the parameters relevant to the experimental turbine and pulse properties, the predicted probability of pulse reflection per blade sweep was P = 0.181 (18.1 %).

*A second calculation determines the likelihood that a bat approaching an operational turbine will be struck by the blades, assuming a constant flight speed and path on approach.?

5 DISCUSSION

The discovery that the ultrasound scattering properties of an operational wind turbine increases with distance, both in the horizontal and lateral aspect, is likely to have significant implications for bat-turbine interaction. Despite the fact that bats have exceptional hearing and can detect echoes much fainter than their emitted pulses, how much attention a foraging bat might pay to a faint echo (*Do we need to assess amplitude of echo here?) while listening for echoes from insect prey is unknown. This is also significant since bats would have to be extremely close to an operational rotor before becoming aware of it as an obstacle that needs to be avoided, which even at a distance of 1 metre away may not provide the bat with much opportunity to alter course and avoid collision. Indeed, this may be even more problematic to the bat approaching a turbine from its lateral aspect, toward the blade tip edges. Our data demonstrate that the blades may not be detectable to a bat at all at a distance greater than half a metre, even when stationary (due to scattering and the highly directional nature of the reflected pulse), since the only discernable echoes are reflected from the hub and not from the blades. In addition, even at closer distances the probability that the outgoing pulses are reflected from the blades themselves rather than the hub is very small (5.3 %), which may not be enough to get through the bat's near-field “attention-gate” (Schnitzler and Henson 1980; Suga etal 1983) on approach, or the bat may simply not be able to comprehend the infrequent nature of the echo. This is a much lower percentage than predicted from *Calculation (1), which expected a pulse echo return rate of 18.1 %. The degree that this figure is reduced compared to what is expected is likely to be due to the high degree of scatter that the pulses are subjected to from the moving blade tips (*and relative amplitude?). The impact of this effect also depends on the rate at which the bat is echolocating; our experiments use a faster pulse rate than a pipistrelle would use under typical ‘scanning’ conditions in free flight (93 ms (Vaughan etal 1997)), as it assumes the bat to be foraging close to the turbine location (bats increase their pulse repetition rate when locating, chasing and capturing prey (Griffin etal 1960)). Recent studies have found bats frequently forage around wind turbines (Horn etal 2008) and a pipistrelle in aerial hawking mode is more likely to be emitting pulses at this increased rate. However, a non-foraging bat on a flight path would be at an even greater disadvantage due to lower echolocation rate and correspondingly lower target detection likelihood. However, it is important to note that at less than 0.5 m to the turbine, the echoes reflected from the blades actually overlap the outgoing pulses somewhat (*see Figure 2). This is critical, because all FM bat species have an in-built safety mechanism to protect their hearing, whereby the muscles of the inner ear close off automatically during pulse emission, for around 3 ms, due to its intensity (Jen Suga 1975). Therefore the bat may only be able to detect the tail end of the echoes from the rotating blades on approach to the turbine. Because of this it is reasonable to assume that bats approaching a wind turbine from its lateral aspect are at a much higher risk of collision than bats approaching from the horizontal aspect.

The rotational velocity of the microturbine, at the equivalent wind speed of 4 - 5 m s^{-1}, was particularly relevant to bats since it has been widely observed that there is a peak in bat-turbine interaction and mortality on low wind speed nights (Horn etal 2008). This relates to *Calculation (1) which demonstrates that the probability of pulse reflection is lower for turbines with a slower rotational velocity. Although many microturbines do not have operational cut-ins (and thus may pose particular risk), most larger scale turbines begin rotating at wind speeds of 3.5 - 4 m s^{-1}. In their study, Horn *et al*. (2008) observed the most bat-turbine interaction at wind speeds between 2 - 5 m s^{-1}. It may therefore be possible to increase the minimum operational wind speed cut-in, blade number and blade width in order to reduce bat-turbine fatalities.

It should be made clear that it is not yet known whether the results found here correlate exactly or relatively to wind turbines on a larger scale. However, it is important to address both problems since bat deaths have been reported not only from large scale turbines but also from microturbines; the BCT (2006; 2007) report findings of bat carcases around several microturbine models including other Marlec Rutland models in the UK.

6 CONCLUSIONS

Microturbine blades turning at a velocity consistent with low wind speed (4 - 5 m s^{-1}) were found to produce echoes for all incoming bat echolocation pulses from a horizontal aspect, with varying degrees of echo intensity, at distances of 0.5 and 1 m, analogous to an approaching foraging pipistrelle bat. Blades were found to reflect less than 10 % of incoming pulses from a lateral aspect at an amplitude where echoes were discernable from background noise levels, which was lower than the predicted figure of 18.1 %, most likely due to a high degree of pulse scatter in all directions from the blade edges. By analysing received echoes, there was found to be no effect on perceived distance to blades (where reflection occurred), observable Doppler shift of frequency of highest energy or pulse distortion other than amplitude reduction due to scatter. It is concluded that microturbines present more of a risk to bats approaching from a lateral aspect (toward blade tip edges) than bats approaching horizontally (toward blade faces). Suggestions for mitigating bat-turbine fatalities include increasing turbine blade number, blade width and increasing minimum wind speed operational cut-ins.

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